SMALL SPHERES IN FOSSIL BONES: BLOOD CORPUSCLES OR DIAGENETIC PRODUCTS?

by DAVID M. MARTILL *and* DAVID M. UNWIN

ABSTRACT. Mineralized spherical structures within blood vessels of an archosaurian (possibly pterosaurian) limb bone from the Lower Cretaceous of the Isle of Purbeck, Dorset, England, superficially resemble blood corpuscles, but are shown here to be pyrite framboids. Slightly weathered pyrite framboids in which the outer surface has oxidized, probably to goethite, may resemble nucleated cells when viewed in thin section. Previous records of so-called blood corpuscles within dinosaur bones may also be of a purely diagenetic origin and should be re-examined.

FOSSIL soft tissues have great potential to throw light on the anatomy and physiology of extinct vertebrates such as dinosaurs and pterosaurs, but accurate identification is vital if the true potential of such fossils is to be realized. Fossilized muscle tissues in dinosaurs were noted first by Nopsca (1930), and more recently by Kellner (1996). Preservation of muscle, dermis and structural fibres of the flight membranes in pterosaurs has been reported from the Cretaceous Santana Formation of north-east Brazil (Martill and Unwin 1989), and Martill (1991) reported the occurrence of organically preserved dinosaur skin (as opposed to impressions) on a scelidosaur (early thyreophoran dinosaur) from the Jurassic of southern England. In these examples, the *in situ* position, topography and morphological complexity confirm that they have been correctly identified as skin and muscle tissues.

Workers have also claimed to have recognized blood corpuscles in fossil bones. As early as the beginning of this century, Seitz (1907) and Moodie (1923) described fossilized blood corpuscles from dinosaurs (see also Swinton 1934, 1970). More recently, Abbey (1977) claimed to have found blood corpuscles in dinosaurian remains, while Schweitzer *et al.* (1996) reported the presence of heme compounds, presumably derived from blood, in a specimen of *Tyrannosaurus rex* from the Cretaceous of Montana. Schweitzer and Cano (1994) figured a number of spherical structures within voids of trabecular bones of *T. rex* which they suggested resembled red blood cells, and illustrated a thin section through one of these structures showing a centrally placed 'geometric structure' which they interpreted as the nucleus of a blood cell (Schweitzer and Cano 1994, p. 317, fig. 3a–b).

Below, we outline a number of problems with regard to the preservation and recognition of blood cells in fossil material. Blood cells are highly labile (more so than other reported soft tissues) and, as such, are special; rapid preservation mechanisms are probably required for their incorporation into the fossil record. It is imperative therefore that structures thought likely to represent fossil blood cells are rigorously analysed, especially as a number of diagenetic mineral phases is known to produce structures that could be confused with spherical cells. Unfortunately, many of the early descriptions of so-called fossilized blood cells are based on thin section petrography and, on its own, this technique is not sufficient for their positive identification. As a minimum, we suggest that the following criteria should be satisfied before a blood cell origin is invoked for such structures within bones: (1), strong morphological similarity to the blood cells of given organisms if known; (2), close size comparability to blood cells in extant relatives; (3), high abundance; and (4), presence of characteristic biomarkers (e.g. heme compounds) within the structures analysed.

Here, we present an analysis of some small spheres, discovered in vascular channels within an archosaurian limb bone, which closely resemble the so-called nucleated blood cells figured by Schweitzer and Cano (1994). The purpose of this paper is to draw attention to the fact that a number of mineral species produced during early diagenesis may adopt a spherical habit. Subsequent alteration during weathering produces a morphology which, when viewed in thin section, can be easily confused with blood cells.

MATERIALS AND METHODS

An isolated, elongate limb bone of an archosaurian reptile (possibly part of a tibia of a large pterodactyloid pterosaur) was collected in a block of ostracod-rich argillaceous limestone from the Durlston Formation, Purbeck Group (Lower Cretaceous) on the foreshore at Durlston Bay, Dorset, southern England (Ordnance Survey grid reference SZ040787–SZ035772; University of Cambridge specimen number UMZC T1305). The Durlston Formation is an important source of Lower Cretaceous terrestrial vertebrates (Benton and Spencer 1995; Howse and Milner 1995), and comprises a series of highly fossiliferous limestones and shales deposited in a range of environments from freshwater to marginal marine and hypersaline lagoons (Allen and Keith 1965). The present specimen lacks either articular end, is oval to flattened oval in cross section proximally and subquadrate in cross section distally. As preserved, it is 200 mm long, with a maximum width of 20 mm proximally, tapering to 12 mm distally. The bone wall is between 3 and 5 mm thick, and there is a well-developed central lumen.

Transverse thin sections were made at two points, 30 mm and 160 mm from the proximal end of the bone. A third, oblique section was made at 100 mm. Three additional pieces of the bone were embedded in resin, lightly polished, mounted on flat aluminium stubs and etched in dilute hydrochloric acid for 25 seconds, sputter coated with gold and examined using a Hitachi 250 L Scanning Electron Microscope. Elemental analyses were performed using energy dispersive X ray analysis (EDAX) with a Link AN1000.

OBSERVATIONS

Thin section petrography shows the bone to be well preserved, with osteocyte lacunae and canaliculi clearly visible even at low magnifications (Text-fig. 1A). A large central lumen is filled with brownish/grey sediment containing some ostracod valves. Vascular channels and other void space within the bone is filled with calcite spar, which is easily removed by etching, and euhedral barite in small, discrete patches. These minerals occur as later stage infills. Visible within the smaller vascular channels of the bone are numerous opaque or slightly translucent spherical bodies with a maximum diameter of 20 μm, but mostly with diameters of 5–8 μm (Text-fig. 1B). Although most of the spheres are opaque, a few have reddish brown translucent margins and, superficially, they resemble cells with a dark, centrally placed nucleus similar to those figured by Schweitzer and Cano (1994).

The spheres are resistant to acid etching (Text-fig. 1C), and scanning electron microscopy shows that they have a crystalline surface texture consisting of aggregated cubes, comparable to that of pyrite framboids (Text-fig. 1D), a mineral habit common for pyrite in marine sediments (Hudson 1982). EDAX analysis reveals the presence of Fe and S only in the spherical bodies, and further shows that these spheres are pyrite framboids. The translucent margins of some examples look somewhat smoother and powdery under SEM; this is a result of slight oxidation of their surface to one of the hydrated iron oxides (most probably goethite).
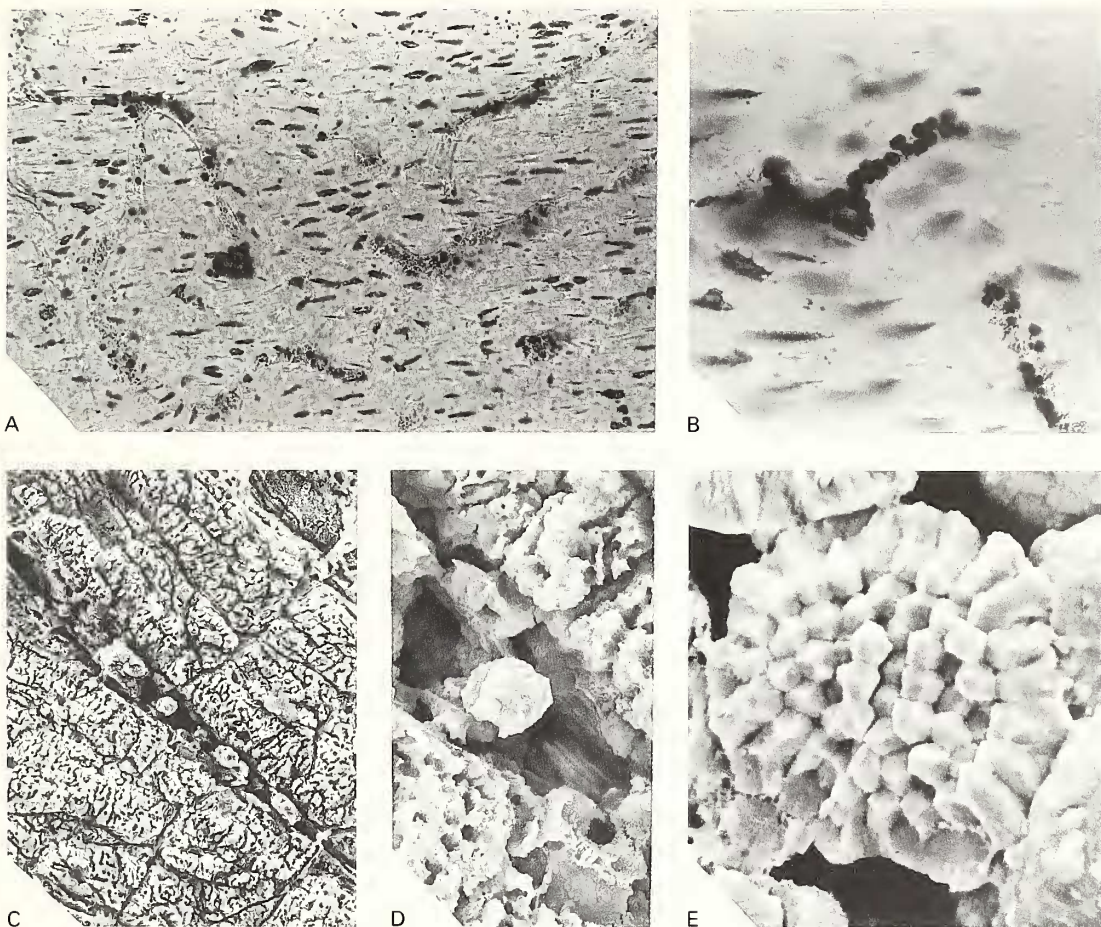
TEXT-FIG. 1. Photomicrographs of thin sections, and scanning electron micrographs of possible pterosaurian limb bone, from the Purbeck Group, Durlston Formation (Lower Cretaceous) of Durlston Bay, Dorset; University of Cambridge UMZC T1305). A, osteocyte lacunae and general fabric of the bone; *c.* ×100. B, as A, showing presence of opaque spherical bodies within microvascular canals of the bone; *c.* ×400. C, scanning electron micrograph of etched surface through bone seen in A; note the framboidal surface texture of the spheres; *c.* ×200. D, scanning electron micrograph of pyrite framboid in C, showing slightly oxidized surface; *c.* ×2500. E, LEIUG DM 70 SEM stub; cross section through pyrite framboid within a coprolite from the Peterborough Member of the Oxford Clay Formation (Jurassic) showing concentric rind of oxidized pyrite, now probably goethite, around unaltered core. When seen in thin section such a structure could resemble a nucleated cell; *c.* ×5000.

DISCUSSION

Fossilized blood corpuscles have been reported in human bone from archaeological sites, where they have been found within vascular canals in bones (Maat 1991; 1993). The preservation of these blood corpuscles is remarkable, in that they appear to be preserved as an organic material, rather than as a mineral replacement, and apart from slight taphonomic damage are morphologically perfect erythrocytes. Here, the morphological complexity is sufficient for the accurate identification of these

structures as fossil blood cells, as no diagenetic mineral has to date been reported with a biconcave oblate spheroidal habit. It is clear therefore, that in archaeological materials at least, blood cells can persist for prolonged periods and remain morphologically intact, but such material is comparatively young, and has not undergone intense mineral diagenesis. Putative blood cells from Mesozoic dinosaurs and other extinct groups must have experienced at least 65 million years in the fossil record, and may have been subject to prolonged mineral diagenesis.

Various features may help to identify fossilized blood cells in dinosaurs, pterosaurs and other extinct groups. Reptilian blood cells are ellipsoidal, and so a close morphological resemblance might be expected between fossil and Recent blood cells. Likewise, blood cells are usually of constant dimensions within species (16.9×9.9 μm for *Caiman crocodilus*, 23.3×13.9 μm for *Sphenodon punctatus*; Saint Girons 1970). The occurrence of numerous similar size bodies might therefore be expected, although morphological transformations and indeed size changes might be produced by taphonomic and diagenetic processes. For example, overgrowths of cryptocrystalline apatite, a mineral species and habit commonly found preserving fossilized labile tissues (Briggs *et al.* 1993), on to a spherical body of only a few micrometres diameter could double the diameter as observed under the electron microscope, and could possibly obscure or even perhaps enhance original surface features. The distribution of putative blood cells within bones or other skeletal elements may also assist in distinguishing between diagenetic products and fossil blood cells, the latter being unlikely to occur, for example, within osteocyte lacunae. Elemental analysis of supposed blood cells may well detect the presence of Fe derived from heme compounds, and S might also be present, released from various amino acids. Incontrovertible evidence of fossil blood might be provided if heme compounds themselves could be detected within the spherical bodies, rather than in bulk bone samples.

Spherical structures have previously been reported from within dinosaur bones in the Wealden Group of the Isle of Wight (Clarke and Barker 1993), but these were composed of siderite, and also barite (Dr M. J. Barker, pers. comm.) and, on the basis of their relationship with other mineral inclusions, these authors concluded that they were of diagenetic origin. Martill (1987) reported the presence of pyrite framboids and euhedral microcrystallites of pyrite within bones of the ichthyosaur *Ophthalmosaurus* sp. from the marine Oxford Clay Formation (Callovian, Jurassic) of central England, that were also of diagenetic origin.

Although the spherical bodies that we describe here from a possible pterosaurian limb bone have a superficial resemblance to a nucleated cell when seen in thin section, and are restricted to vascular channels within the bone, we do not consider that they represent fossil blood cells. Features which support this conclusion include the variable size range (5–8 μm, dimensions somewhat smaller than those of the erythrocytes of modern reptiles; Saint Girons 1970), an elemental composition consistent with pyrite, one of the most abundant early diagenetic mineral phases in marine sediments, and a surface morphology identical to that of framboidal pyrite (Hudson 1982).

Blood corpuscles in dinosaur bone reported in early accounts not based on scanning electron microscopy, e.g. Seitz (1907), Moodie (1920, 1923) and Abbey (1977) may also have been diagenetic products. Seitz (1907) described biconvex structures with flat surfaces as possible fossilized blood corpuscles, but expressed some reservations about this interpretation. His description of the structures is also consistent with the external morphology of pyrite framboids. Likewise, Moodie (1920), after publishing his description of fossilized blood corpuscles, noted that he would not have published his observations, had he been aware of Seitz's (1907) reservations (Moodie 1923).

More recently, Schweitzer (1993) reported the presence of small spherical objects within vascular canals of bones of the dinosaur *Tyrannosaurus rex*. These were described as 'cell-like' and 'primarily of iron' (we suspect that the author meant contained Fe, as analytical techniques using SEM are generally quantitatively unreliable). Later, Schweitzer *et al.* (1996) noted the presence of heme compounds within the same dinosaur specimen. It is therefore possible that some of the Fe from haemoglobin remains as a breakdown product within fossil bone, although this has yet to be demonstrated. It is also possible that Fe from haemoglobin is liberated by bacteria during decay, and becomes available for early pyrite production. However, we suggest that such material should

be examined by scanning electron microscopy and EDAX elemental analysis to determine the true nature of any spherical bodies thought to be fossilized blood.

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DAVID M. MARTILL

Department of Geology
University of Portsmouth
Burnaby Road
Portsmouth PO1 3QL, UK

DAVID M. UNWIN

Department of Geology
University of Bristol
Wills Memorial Building
Queens Road
Bristol BS8 1RJ, UK